7.—THE VOLCANIC HISTORY OF WESTERN AUSTRALIA.

PRESIDENTIAL ADDRESS

By

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"To discover order and intelligence in scenes of apparent wildness and confusion, is the pleasing task of the geological inquirer."

GENERAL.

The Report of the Council, together with the Treasurer's Financial Statement and other items of interest relating to what may be called the business side of the Society's transactions, which have already been submitted to you, render it quite unnecessary for me, as your President, to make any further allusion to the material aspects of your affairs.

AUSTRALASIAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

I feel that I should be wanting in my duty to you and to the very broad domain of science, were I at the outset of this evening's proceedings to pass over without notice the most important event in the scientific world of Western Australia during the Royal Society's year which has just closed, viz., the visit of the Australasian Association for the Advancement of Science to the State in the months of August and September last. This being the first time that the Association has met on the western seaboard of the continent, the meeting consequently marks an epoch in the development of science in Western Australia. That the Association should have decided to hold its eighteenth meeting in Perth, so far removed from Australia's chief centres of population, is a compliment to the State and a distinct recognition of the efforts of the relatively small band of scientific workers in this large, young, and, as yet, comparatively undeveloped country. The liberal financial and other assistance given by both the State and Commonwealth Governments and private individuals towards the visit of the Association is a matter for gratification. We, as the premier scientific society in Western Australia, are not unmindful of this and appreciate to the full the aid thus afforded.

The public welcomed the visiting members of the Association with characteristic cordiality and hospitality. The meeting was favoured with good weather, and as the carefully-considered programme left little to be desired, the visiting scientists carried away with them very pleasant memories, whilst socially the meeting proved to be everything that both guests and hosts alike could have wished.

The Modern School, where the meeting was held, proved very satisfactory; it would, in fact, have been difficult to find at the time a building and grounds better adapted for such a rendezvous.

The various sections, fifteen in number, were well attended, many valuable papers were read, and several important intersectional discussions on scientific problems took place. The sectional meetings offered so many subjects of absorbing interest that it would be difficult to say which proved the most generally attractive.

The excursions were all that could be expected of such enterprises. They were well managed, ably led, and presented a wide range of instructive scientific phenomena.

As far back as January, 1907, it was pointed out at the Adelaide meeting of the Association that "the civilising value of scientific investigation such as is evidenced by a gathering of this kind, where the men from the East meet those from the West upon common ground for the purpose of discussing and recording the work of the past, must tend to link all parts of the continent together, and time will perhaps show that it may fall to the lot of the Australian men of science to materially assist in the solution of the problem of preserving those harmonious relationships and in the strengthening of those ties which are so severely taxing the combined resources of political diplomacy." It is for others to judge as to the extent to which the brotherhood of science has played through the visit of the Australasian Association for the Advancement of Science to the State, in promoting an *entente* destined to be of lasting benefit to Australia, in addition to acting as a much needed stimulus to the local development of scientific inquiry.

THE VOLCANIC HISTORY OF WESTERN AUSTRALIA.

In the address which it was my privilege to lay before you at our last Anniversary, 12 months ago, I gave, though only in the very briefest outline, what seemed to me the main contributions which Western Australia has made to the general principles of geological science.

Within the limitations imposed by the traditional requirements relating to the address of a retiring President, I purpose on this occasion taking up a portion of that narrative and devoting a very short period to a review of the present condition of our knowledge of the volcanic history of Western Australia.

Igneous action has played a very important part in the geological history of the State for the evidences of volcanicity have been manifest over a protracted interval of geological time, and none ranks higher in importance and general interest. The main groups of igneous rocks are represented over widely separated areas, both amongst the intrusive and extrusive rocks of different geological ages; the earliest beginnings go back into the Archaeozoic period, and the final manifestations did not cease until late Tertiary or perhaps later times. The volcanic history of the State thus divides itself into two widely separated periods. The first embraces the vast Palaeozoic and Archaeozoic ages, whilst the second falls entirely within the Tertiary period. Between these two periods is the prolonged interval of Mesozoic time during which, so far as investigations have been carried, no trace of contemporaneous volcanic action is known. In this respect Western Australia only illustrates that general quiescence of volcanic energy which finds a striking parallel in other regions of the globe, more especially over the greater portion of the European continent. The subject of igneous action in Western Australia is important, not only from the more or less local interest which attaches to its various manifestations, but also from the fact that its geological history involves much that is fundamental to the science generally, besides being of considerable value, for nearly all the ore deposits have a very intimate connection with igneous rocks, and their differentiates while the decay of many of them results in the formation of rich soils. The known mining districts in Western Australia and elsewhere occur in the immediate vicinity of igneous rocks, or in those areas in which the chief characteristics point to prolonged volcanic activity in its many forms and of varying degrees of intensity.

The volcanic products are, according to their mode of origin, divisible into two main groups; some were formed from congealed molten matter, which forced its way either along the planes of bedding or across the strata in the form of intrusive sheets or dykes, whilst the others were contemporaneous with the deposition of the associated sedimentaries and include outpourings of lavas, ashes, and other volcanic ejectmenta thrown out from numerous and widely separated centres of eruption, of which the remains at present exist, submerging fairly large areas of country.

The volcanic rocks have been investigated from the stratigraphical, petrographical, and chemical sides and a vast amount of data made available, chiefly through the official publications of the Geological Survey and the Chemical Branch of the Mines Department.

The interpretation of the volcanic history of Western Australia is only possible after the true order of succession of the rocks, which have preserved the memorials of igneous activity from the earliest of geological times, has been arrived at. As the later of the geological periods the record ought, under ordinary circumstances, to be the easiest part of the State volcanic history to interpret, for the reason that the conditions being less remote from those prevailing at the present day, have suffered far less destruction and transmutation than those of the older geological periods.

In the extreme South-Western portion of the State evidence of extensive basaltic eruptions of Miocene Tertiary Age cover an area of about 3,000 square miles.

The basaltic flows, when of sufficient thickness, cracked during cooling into characteristic columns or forms; they weather out into steps along their vertical joints, and their terraced outcrops are to be seen in the low-lying land on the seacoast at Bunbury and elsewhere on the South Coast. The basaltic rocks of Bunbury are exposed as a narrow fringe for about a mile along the shore, with a width of about 100 yards, and in no place do they rise more than a few feet above high water mark. One of the lava flows proved, as determined by boring operations at the Bunbury Brewery, to be 97 feet thick. It was pointed out by Mr. F. J. Gregory, in the year 1861, that basalt again made its appearance about four miles to the South of Bunbury, at 20 miles it was exposed in the bed of the Capel River, and finally cropped out in a continuation of the same line on the South Coast to the Eastward of Flinders Bay. The Bunbury basalt and its south-easterly extensions, in the valley of the Blackwood River, and near Black Point on the South Coast, are mere fragments of the great Tertiary lava plains that occupied such a large part of the region of the South and Eastern Australia, the foundering of the western portion of which has left the few relics above sea level and on these erosion has not yet had time to be very active.

The volcanic eruptions probably began somewhere about the close of the Miocene Tertiary Period and terminated prior to the Pleistocene epoch. During the interval, which geologically is a relatively short one, there was time for the accumulation of these large flows. This remarkable collection of volcanic material has remained until the present time with its original horizontality of bedding but slightly disturbed. Until these lava flows have been dissected by the weather, there is very little visible evidence of the masses of basic rocks, which almost certainly lie below the surface and constitute the magma from which the basalts emanate.

The Miocene beds of the Southern coast are intersected by dykes of dolerite, which may possibly be in some way connected with the basalts, thus affording a clue to the age of the volcanic activity.

The effects of this Tertiary vulcanism have been felt to a more or less marked degree in the goldfields areas in those portions of the State near the western shore line of the great Miocene Gulf, which extended far into the interior, and of which the Great Australian Bight, is but a relic.

The various scattered intrusive veins and dykes of dolerite, some of which contain olivine occurring in the Dundas Goldfield and elsewhere, in all probability belong to the same period of Tertiary igneous activity as the basaltic lavas. One of the dolerite dykes is seen traversing the gold-bearing quartz reef at the 145-feet level in the main underlay shaft of the Cumberland Gold Mine at Norseman. The newest igneous rock on the Dundas Goldfield is the remarkably fresh intrusive norite varying from a mile to half-a-mile wide, and which has been followed across country for a distance of at least 12 miles in an east and west direction. This dyke crosses the western shores of Lake Cowan, but has not yet been followed in that direction. A very suggestive feature in connection with this norite dyke is that its southern margin on the western side of Lake Cowan, has changed towards a peridotite.

In the country at the northern end of Lake Cowan there are olivine-dolerite dykes in a good state of preservation which may also represent smaller satellitic intrusions related to the Norseman norite which has been found to extend to the northern end of the Fraser's Range. Serpentines, the alteration products of peridotite, are of frequent occurrence in the country surrounding the Miocene sea; they contain veins and masses of dazzling white magnesite and opal's poor relation, chalcedonic silica, which result from attacks by water and carbonic acid of deep-seated origin.

The very great similarity in geological structure and constitution existing between the country bordering the Indian Ocean and Western Australia has repeatedly been stressed; it is therefore quite possible that the suggested connection between our southern basaltic lavas and the olivine-dolerite dykes and masses of serpentine bearing peridotites, find their chronological parallel in the ultra-basic relatives of those late Tertiary basaltic lavas which constitute such an important feature in Indian Geology.

The basic dykes and the basaltic lavas of the south-western portion of the State appear to belong to one series and reached their present position at about the same geological period. All the available evidence, therefore, points to the fact that they belong to the same geological era as the relatively recent volcanic rocks of South Australia and Victoria, viz., late Tertiary.

The Tertiary era has, as is well known, been one of pronounced activity over the south-western corner of the State, but no igneous rocks of this age have so far been recognised anywhere else in Western Australia, except in the Kimberley Division, near to that great circle of fire which forms a part of the festoon, round Northern Australia, traceable from the Himalayas, through the Malay Peninsula, the East Indies and New Guinea; the outer regions, lying to the southward of the northmost portion of the mainland of Australia, of which have been subjected to volcanic activity.

Basic lavas and ashes of Tertiary age occur in great force in Kimberley. These appear in the valleys of the Ord and Bow Rivers to have levelled up the depressions of the old land surface, except for certain knife-edged ridges of the older rocks, which still protrude above the general level. On the Behn River, just above what is known as the Gorge, a dome or "puy" basalt, which formed one of the foci from which the lavas issued, has been noted.

In the King Leopold Plateau, in the far north, the volcanic beds occur in great force, and form the highest part of the country. At Mount Hann, a very remarkable cliff-faced mountain, situated on the highest summit of the Plateau, dissected by the waters of the King Edward, the Drysdale, and the Prince Regent Rivers, the volcanic rocks are well exposed. The cliffs formed by the faces of the lavas and ashes rise perpendicularly from 100 to 300 feet in height. From the summit of Mount Hann the great extent of the volcanic rocks could be seen.

In the vicinity of Synnot Creek, on the King Leopold Plateau, is a remarkably coarse volcanic breccia covering a wide area, associated with lava flows. The coarse breccia or agglomerate occupies the throat of one of the volcanic vents which has not yet entirely disappeared by denudation; it is surrounded by lava flows and fine-grained volcanic ashes.

Leucite-bearing rocks have been met with in the Fitzroy Valley, where they occur in the form of volcanic necks, penetrating the carboniferous strata consisting of sandstones, shales, grits, conglomerate boulder beds and limestones, which have been gently folded, certain of the beds being arranged in a series of anticlinal folds of low amplitude whose main axes trend generally north-west and south-east. These volcanic necks are, in the middle basin of the Fitzroy River above Liveringa, sometimes associated with small local flows of leucite-bearing lavas. The easternmost occurrence of these alkaline rocks is at Christmas Creek in Lat. 19° South, and the most westerly near a hill about 13 miles north-west of Mount Wynne. They intrude rocks which have been affected to a slight extent by trough faulting. The necks and plugs have hardened and baked the shales, whilst according to the researches of Mr. Blatchford, the sandstones and grits have been vitrified to such an extent as to form a glass. These leucite-bearing rocks are particularly rich in potash. Petrographically these Kimberley leucite-bearing rocks very closely resemble those found in the islands of Borneo, Sumatra, and the Dutch East Indies. The leucite rocks which are found in several places near the north coast of the eastern portion of Java are believed to be of late Tertiary Age, agreeing in this respect with the Western Australian occurrences.

There is a hot spring issuing from the carboniferous sediments in the watershed of the Fitzroy, near Mount Wynne, in such a geological situation as connects it with the main tectonic lines of the district, and which would seem to point to the fact that this Tertiary igneous activity has not yet been entirely suppressed.

A long period of quiescence preceded the Tertiary period of intense volcanic activity, for no definite evidence of contemporaneous igneous rocks covering the time interval between the late Tertiary and the Permo-Carboniferous eras has been noticed in Western Australia.

Igneous rocks, provisionally assigned to the Ordovician (?Pre-Cambrian) period, occur in South Lat. 26° in the Townsend Range near the South Australian border. The formation is made up of ashes, marine quartzites, calcareous grit, and conglomerate associated with interbedded vesicular basaltic and dolerite lavas. It is interesting in this connection to note that igneous rocks of apparently the same age have been noted in South Australia.

Strata of undoubted Cambrian Age are known to occur in the Kimberley Division, where they extended over a very large area of country. During this age there ensued a period of volcanic activity resembling that of the Ordovician, though in increased volume, especially in the extreme easterly portion of the district, in S. Lat. 18°, near the South Australian border. The Great Antrim Plateau, which covers such a large area, is made up of bedded basic lavas of this geological age.

The most active centres of eruptive energy found anywhere in Western Australia occur in that group of rocks designated the Nullagine Formation, which is, perhaps, the most widely spread of any of the rock systems exposed in the State, as well as in some respects one of the most important.

The precise position which the formation occupies in the geological column is as yet one of the many unsolved stratigraphical problems in the State. None of the beds in the Nullagine Formation, despite the fact that the magnesian limestones are of marine origin, has as yet yielded any fossils, hence any correlation of the strata based upon palaeontological data can, in the light of our present day knowledge, be little else than tentative. The significance, however, of fossils in attempting to establish contemporaneity of formations, or the determination of geological age in relative terms, has, it is to be feared, often been unduly emphasised and somewhat incautiously employed. Organic factors are strongly influenced by, if not almost entirely dependent upon, physical conditions. Lithological peculiarities and the succession of associated rocks, together with the physiographical and diastrophic history, furnish criteria which have proved to be of exceptional value in geological correlation.

The Nullagine Formation has hitherto been assigned to the Pre-Cambrian Period, though it has been suggested that it may be Ordovician Age. Lithologically the strata consist of a great group of sedimentary rocks, sandstones, quartzites, conglomerate boulder beds and magnesian limestone, associated with which are numerous igneous rocks. Some of these were formed from congealed molten matter, crystallising as dolerite, which forced its way either along the planes of bedding or across the strata in the form of intrusive sheets, sills or dykes, whilst others were contemporaneous with the deposition of the associated sedimentaries and include outpourings of lavas, ashes and other volcanic ejectmenta. From numerous and widely separated centres of eruption of which the remains at present exist, lavas and ashes were thrown out, submerging fairly large areas of country. So far as researches in the field have been carried, the volcanic foci all seem to be situated along or on the northern portion of the area in proximity to what would appear to be the shore line of a gradually receding ocean. The very great extent of the lava flows and associated ejectamenta seem to imply that these centres of eruption must, during Nullagine time, have appeared as a remarkable chain of coastal volcanoes, but whether they are distributed along lines of orographic movement is one of those as yet unsolved problems of Western Australian geology.

The occurrence of sandstone, quartzite and other sediments interbedded with lava flows, etc., points to the fact that some of these volcanic eruptions took place under water and must have been followed by intervals during which sedimentation was carried on.

These volcanic beds occur in great force in the King Leopold Plateau in Kimberley, and form the highest parts of the country; whilst in certain localities they reach a considerable thickness, often over 500 feet.

As a rule these lavas have the mineralogical composition of basalts or dolerites, though in certain parts, such as Mount Anketell, West Pilbara, they are closely allied to augite-andesite; while at Bamboo, on one of the tributaries of the Coongan River, acidic lavas, quartz felsite, rhyolite, occur near the base of the formation. The steam holes in many of the amygdaloidal lavas are filled with secondary minerals, partly chalcedony and partly calcite.

The widespread occurrence of these lavas and their associates, together with the relatively few volcanic focii so far noticed, would seem to imply that fissure eruptions played an important part in the formation. This type of vulcanism finds a parallel in the 200,000 square miles occupied by the Cretaceous Deccan Trap areas of India and those extensive lava plains of Northern Queensland which I have been privileged to examine.

A very important feature in the region occupied by, and adjacent to, the Nullagine Formation is the abundance of dolerite intrusions. Those dolerites have a remarkably uniform composition, and wherever they have been examined they exhibit little or no trace of recrystallisation or other signs of metamorphism. Occasionally a glassy selvage, due to rapid cooling, may be noticed occurring at the contact between the dykes and the rocks they traverse.

The dolerites seem to be in practically the same condition in which they originally congealed, and no great terrestrial disturbance seems to have affected the region since the time of their injection.

The dyke rocks are all readily distinguished by their dark-greenish colour, a rusty and, in places, exfoliating weathering. Some extend across country in more or less straight lines for many miles and give rise to fairly conspicuous features standing out boldly on the back of the ridges. In some cases these dykes may be seen invading the sedimentary rocks along the planes of bedding; occasionally an effect of the igneous intrusion an arching up the overlying strata may be noticed. On the northern face of the plateau, in the watershed of the Maitland River in the West Pilbara Goldfield, there may be seen a splendid example of one of these dolerite dykes, cutting the horizontal strata transversely. These basic dykes may also be seen at other localities outside the limits occupied by the Nullagine Beds; they have been noticed in mine workings.

There is as yet little definite evidence as to the nature and composition of the parent magma, from which these igneous rocks were derived, nor any adequate explanation as to why the rocks are acidic in composition in some localities and basic in others. As regards the problem connected with the relative age of the lavas, ashes and the dykes, there is as yet but little direct evidence; it is, however, quite possible that they may be grouped together into one series, which may be held to represent one distinct place of the volcanic phenomena of the State during Nullagine time.

The Nullagine Formation rests with a very violent discordance upon the older Archaeozoic rocks, and is made up in very large part of material derived from the rocks of the ancient continental land surface, which was evidently exposed to prolonged denudation prior to the deposition of the Nullagine beds.

The geological formation of pre-Nullagine times is entirely confined to the most ancient epoch in the history of the earth's crust of which we have any visible and tangible record, and belong to a very remote and hoary past, furnishing as it does evidence of the processes of world-making and contains relics of the remote conditions when the crust yielded to the almost inconceivable earth force.

The rocks of pre-Nullagine times, constituting, as they do, the foundation stones of Western Australia, are of such a nature as point to prolonged igneous activity, and have shared in those intense terrestrial disturbances which must have been carried on over a very considerable lapse of geological time. It is under any circumstances a difficult task to decipher the records of the rocks in such a way as to interpret the sequence of events in the past volcanic history of any country. It is especially so in the case of such a vast and remarkable assemblage of igneous rocks and other differentiates and constitutes by far the largest mass of the Archaezoic formation. These have been so well described by Mr. de C. Clarke, in his Anniversary Address on the Pre-Cambrian System in Western Australia, delivered in July, 1923, that it is unnecessary on this occasion to retraverse the same ground, more especially as in the address, which I was privileged to submit to you at our Annual Meeting last year, a resumé of the igneous activity of this period and its economic aspects was presented.

It was, *inter alia*, pointed out that a dominant feature was the intrusion of batholiths of granite with their satellitic differentiates in such a gigantic scale as almost entirely to overshadow that of the earlier sedimentary and igneous formations, and that such represented the most important event in the Pre-Cambrian geological history of Western Australia.

The pegmatite veins contain some of the rare uranium-bearing minerals as their accessory constituents, which afford a means of determining their minimum geological age in terms of years, though such, until comparatively recently, proved a very formidable tax upon geologists' arithmetic. Calculations based upon the quantities of lead and radio-active elements occurring in the pegmatite dykes of Wodgina in the Pilbara Goldfield, give their age as 1,260 million years. These dykes invade a series of highly metamorphic sedimentary rocks associated with contemporaneous lavas and ashes; hence these beds which were in existence prior to the pegmatite intrusions must be of considerable antiquity, and they must at least be much older than the period of years just mentioned.

The problems of the source of molten magmas, the causes and mechanism of the manner of their ascent to the surface, the origin of the different types of magma and other aspects of the natural history of the igneous rocks, provide abundant opportunities for both collective and individual research and leave a very wide field open for investigation.

The rapid review of igneous activity in Western Australia has now been completed. During the course of this brief excursion amid the abysses of geological time a very passing glimpse has been given of the changes in the volcanic activity, which was rife during the different periods of Western Australia's geological history.

While we scan the surface of the State as it at present appears, its features seem instinctively to melt away into visions of what it once has been, and we then come to feel the force and realise something of the meaning of the exclamation in the Book of Job that, "Man putteth an end to the darkness, and exploreth to the utmost limit the stones of darkness."